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MULTI-SENSOR FUSION TECHNIQUES FOR REMOTE SENSING

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ABSTRACT

The benefits of classical remote sensing techniques have reached a plateau as far as their ability to determine certain scene parameters. Simple techniques of combining sensor outputs have not resulted in any appreciable improvement in the results. Statistical analysis techniques of sensor response have also reached their peak effectiveness, and any further improvements in this type of data reduction may not be possible. Sensor fusion must go beyond present linear combinations of data or conventional predictions based on these techniques.

The ultimate objective is to estimate scene/object parameters from sensor data obtained at any time, location, and under varying environmental conditions. These parameters may typically include surface roughness, dielectric constant, temperature, shape, size, orientation and chemical composition. The possibility of such estimation under various environmental conditions is explored in this paper. It is based upon the principles of reflection, emission, absorption, and scattering properties of the scene/object, including the interaction of illumination and material composition.

The goal of sensor fusion advanced in this study is to integrate outputs of various sensors with the methods of mathematical physics to realize the synergistic results. This approach also allows estimating additional parameters which could not be determined by using separate sensors. In some cases, higher accuracies are achieved than those based upon computations of data inputs from individual sensors. The results of this analysis show future promise in improving sensing techniques.

Keywords: Remote Sensing, Sensors, sensors, Data Reduction, Environment, Earth Observation.

I. INTRODUCTION

The observation of Earth and other planets continues to gain momentum as unique processes and phenomena are revealed. More significantly, these observations provide synoptic views of large areas with atmospheric, surface, and sub-surface parameters. The advantages of remote sensing have been established through the efforts of many organizations and nations.

On the basis of these studies, the National Aeronautics and Space Administration (NASA) has identified Mission-To-Planet-Earth (Ref. 1). In this program, the unique vantage points of space can be used to observe/sense Earth's features, atmosphere, and biota that is unattainable by other means.

In general, remote sensing consists of four general areas: 1) Sensors and associated technology, 2) Science associated with the interaction of audio/electromagnetic spectrum with objects and scenes, 3) Data corrections and processing, and 4) Application of sensing methodology to the detection and monitoring of specific phenomena and processes.

Sensing technology is progressing substantially with increased sensitivity at optical wavelengths, new and improved laser and infrared sensors, and imaging active and passive microwave sensors. Bistatic and monostatic sensors with frequency, polarization, phase, and the angle of incidence/observation diversity are being developed for sensing surface, subsurface, and environmental parameters (Ref. 2).

Further progress will need to be made in sensing technology to assure the perception of objects, scenes, and processes regardless of distance, lighting conditions, and the surrounding environment.

In general, key sensory data will be needed for the three-dimensional scene/object descriptions, including location, orientation, motion, chemical, physical, and surface/subsurface properties. The ultimate goal of any vision/sensing system is to extract object/scene parameters from raw sensory data obtained at any time, location, and environmental conditions. These parameters include surface roughness, dielectric constant, and temperature or more complex features such as shape, features, chemical composition, and location.

The possibility of such assured vision happening rests on the understanding of the reflection, emission, absorption, and scattering properties based on physical interaction of illumination and the material properties of the scene/object.

The goal of sensor fusion is to combine output of various sensors using known physics and chemistry processes to produce a view that is improved over the views of the component sensors. This includes determining more parameters and/or increasing the accuracy of detection or prediction (Ref. 3).

II. SENSOR FUSION METHODOLOGY

The benefits of classical sensing techniques using routine sensors are rapidly reaching a plateau. Simple addition, multiplication, division, and subtraction have failed to produce dramatic results. Standard statistical analysis of sensed data has, likewise, peaked as an effective data reduction technique.

New sensing technology and techniques offer possibilities beyond what is now available. Besides these new developments, sensor fusion which goes beyond linear manipulation of data or conventional statistical predictions, offers a powerful tool for sensing and perception. One such novel approach has been advanced through U.S. Patent 5,005,147 issued in 1991 (Ref. 4).

The technique involved re-constructing an object that was partially shadowed, thus making optical recognition virtually impossible. The flawed optical image was supplemented with object backscattering cross sections collected with an active microwave radar.

Iteratively generated predictions of radar cross sections (RCS) using the flawed optical object description were compared to the observed values. The surface model was increased and decreased successively, and comparisons continued. As these comparisons narrowed the margins between the actual and calculated values of RCS, the object surface model improved.

For simple objects such as spheres, spheroids, and plates, the surface can be predicted very accurately (see Figure 1.).

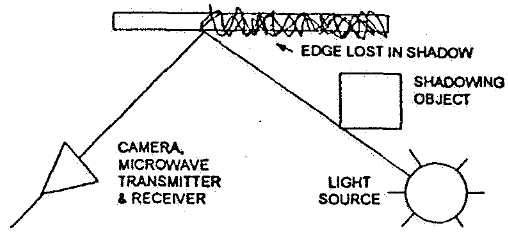

Fig. 1 *Microwave Radar and Optical Sensor Fusion*

The RCS comparison was accomplished using the method of moments. The method required some initial shape which was provided by the optical sensor. The result was greater than either sensor could estimate since RCS inversion techniques do not necessarily yield unique solutions.

This concept can be extended to complex situations by executing several steps. A crucial and first step is to assimilate all information pertaining to the object/scene. For scenes on the Earth, time, date, and location of the scene can be used to calculate the incident illumination due to the sun.

Furthermore, previous knowledge of the scene can also be used. For example, when updating the map of a location on the Earth, previous maps can be used. The scene illumination can be calculated from the position of the moon and the sun relative to that of the Earth. These initial details can be extended to provide estimates of temperature and emissivity using Planck's Law and the Rayleigh-Jeans approximations. These initial estimates can be used to identify the best modes and configurations for the deployed sensors. Sensor fusion will guide these decisions through the process shown in Figure 2.

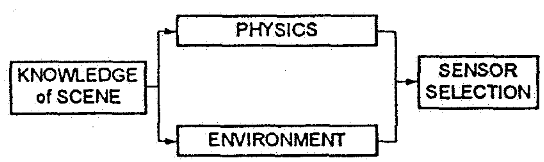

Fig. 2 *Sensor Selection Based On Physical Module*

This step involves the calculation of scattering and emission patterns using Maxwell's equations and appropriate boundary conditions. These calculations can be used for the selection of active and passive imaging and non-imaging sensors. The sensors include microwave, millimeter wave, laser, infrared, and optical types. The operating frequencies, polarization, and look-angles for these sensors can also be selected for the object/scene viewing. This selection provides the initial estimation of the required parameters.

The laser scanner can be utilized as an initial estimate for the velocity and orientation of the object. This can be followed by another sensor such as an active microwave radar to estimate the roughness of the scene/object. Once some roughness estimate is made, a radiometer can be used to estimate the dielectric constant. The dielectric constant, along with the initial value of the incident radiation can then be utilized to select appropriate infrared sensor to map the scene/object.

In the last step, if the optical image is available, the data can be fused to provide the synergism needed to refine the estimates of roughness, dielectric properties, and temperatures. The overall flow is briefly shown in Figure 3.

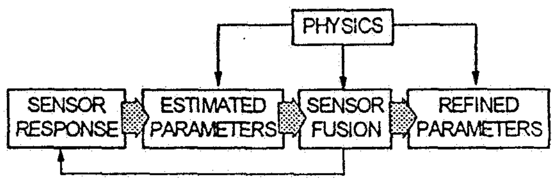

Fig. 3 *Refined Parameters Using Sensor Fusion*

The fusion of data including sensor information takes into account physical scattering and emissivity models and estimates more accurately the object/scene parameters and/or provides new parameters that could not be estimated by the sensors on an individual basis. For example, the fusion of active and passive microwave data could lead to the estimation of roughness, dielectric properties, and the root mean square height distribution.

In summary, the technique developed offers: 1) aid in the selection and configuration of sensors, 2) provides more accurate measurement of scene/object parameters, and 3) provides more parameters than is possible using sensor data without fusion.

III. RESULTS

Multi-sensor fusion can be difficult and costly if the algorithm development is carried out using experimental data. A cost-effective approach is to use computer simulation to assess the feasibility of fusing multiple sensors. The initial work was the development of AVISION software for demonstrating sensor fusion capabilities in a lunar outpost scenario (Ref. 5,6).

In the recent past, AVISION was modified to study satellites in low-Earth orbit for space operations. AVISION is a graphically oriented system implemented on Silicon Graphics workstation. It uses models of objects created with another NASA software tool, the Solid Surface Modeller, to perform sensor simulation.

The user can create a computer model of an object or scene and a data file of associated known properties. These attributes are stored in the Environment Module. AVISION uses a ray-tracing algorithm to generate a false-color image of how various sensors would image the scene/object. The architecture of the software is shown in Figure 4.

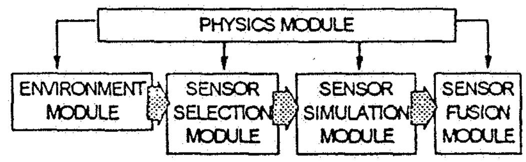

Fig. 4 *Software Architecture for AVISION*

AVISION, itself, is a collection of modules which can be modified to suit the sensing scenario. For terrestrial settings, the Environment Module and some elements of the Physics Module must be changed to match external conditions.

The present architecture was evolved for low-Earth orbit satellite monitoring from the lunar outpost model. The computer programming was done by Mr. Charles Beauduy under the guidance of the author. For precise data on the position of Earth, moon, and sun, we incorporated information from an orbit propagation system developed by McDonnell Douglas Corporation.

For flux/temperature calculations on the hypothetical satellite, we used TIMES89, a thermal analysis tool offered by NASA Johnson Space Center. This algorithm calculates flux and temperature for satellites in low-Earth orbit.

Early results using AVISION are promising. For example, the simulated infrared sensor makes an initial prediction of surface roughness based on dielectric constant and temperature. This prediction serves as an input to a simulated passive microwave sensor which makes an improved estimate of dielectric constant using emission models. The process iterates until the estimated parameters are more accurate than any one of these sensors could predict. A similar interdependence was studied between like and cross-polarized returns for an active microwave sensor. Experimental verification of these results is planned for the future. These verifications will also be used to modify various modules for the final architecture.

IV. CONCLUDING REMARKS

The sensor fusion described in this paper advances the state of the art by using unique algorithms based on physical models of scattering and emission from space objects and scenes. We plan to use this method for remote sensing of the Earth—its land, water, and atmosphere.

The ultimate objective is to be able to switch sensors automatically according to the parameters that need to be estimated through observation. Currently, these models are being refined at the Johnson Space Center, and experimental verification plans being developed for the multi-sensor fusion using laser, optical, visible infrared, microwave, and radiometer data (Ref. 7).

V. ACKNOWLEDGMENT

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